EFFECT OF HIGH TEMPERATURES ON FECUNDITY AND FERTILITY OF SIX LEPIDOPTEROUS PESTS OF COTTON IN ARIZONA

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Effect Of High Temperatures On Fecundity And Fertility Of Six Lepidopterous Pests Of Cotton In Arizona

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SUMMARY

A study was undertaken to determine what effect various periods of high temperatures would have on the fecundity and fertility of six lepidopterous pests of cotton in Arizona. These Lepidoptera included the bollworm (*Heliothis zea* (Boddie)), the tobacco budworm (*H. virescens* (F.)), the beet armyworm (*Spodoptera exigua* (Hübner)), the cabbage looper (*Trichoplusia ni* (Hübner)), the salt-marsh caterpillar (*Estigmene acrea* (Drury)), and the pink bollworm (*Pectinophora gossypiella* (Saunders)).

Daily exposures at 35° C. of larvae, pupae, and adults for 2, 4, and 8 hours decreased the development period as the exposure was increased. The fecundity, fertility, and longevity were not affected. Exposures at this temperature for 16 hours reduced fecundity, fertility, and longevity.

Daily exposures at 40° C. of larvae, pupae, and adults for 2 and 4 hours did not affect their development, fecundity, and fertility. Exposures at this temperature for 8 hours increased the development period and reduced fecundity and fertility. When larvae and pupae were exposed to 40° for 16 hours, development was poor and fecundity and fertility were drastically reduced. When adults were exposed to this temperature for this period, fecundity, fertility, and longevity were generally reduced.

INTRODUCTION

During extended periods of hot weather in Arizona many cotton insect pests fail to develop populations large enough to be injurious to cotton. However, late in the season cotton plants shade most of the soil surface and become large enough to modify the temperature within the canopy where injurious populations may develop.

The effects of high temperatures on the development and mortality of the boll weevil (*Anthonomus grandis* Boheman) were reported by Fye et al.[2] R. E. Fye and W. C. McAda (unpublished) noted that high temperatures affected the development of six species of Lepidoptera injurious to cotton in Arizona and indicated that the high temperatures in programed regimes had a deleterious effect on the fecundity of several species.

A study was undertaken to determine what effect various periods of high temperatures would have on the fecundity and fertility of six lepidopterous pests of cotton in Arizona. These included the bollworm (*Heliothis zea* (Boddie)), the tobacco budworm (*H. virescens* (F.)), the beet armyworm (*Spodoptera exigua* (Hübner)), the cabbage looper (*Trichoplusia ni* (Hübner)), the salt-marsh caterpillar (*Estigmene acrea* (Drury)), and the pink bollworm (*Pectinophora gossypiella* (Saunders)).

METHODS AND MATERIALS

Newly hatched larvae, from which the moths were reared, were drawn from cultures of the Cotton Insects Biological Control Laboratory, Agricultural Research Service, Tucson, Ariz. For several generations wild stock has not been introduced into the cultures. Newly hatched larvae of the larger species were reared in 1-ounce cups of lima bean medium[3] and the smaller spe-

[1] The authors gratefully acknowledge the assistance of John F. Edwards, biology research technician, Bee Research Laboratory, Agricultural Research Service, in the dissections and microscopic studies.

[2] Fye, R. E., Patana, R., and McAda, W. C. Developmental periods for boll weevils reared at several constant and fluctuating temperatures. Jour. Econ. Ent. 62: 1402–1405. 1969.

[3] Shorey, H. H. A simple artificial rearing medium for the cabbage looper. Jour. Econ. Ent. 56: 536–537. 1963.

cies in $\frac{9}{16}$-ounce cups. The developing larvae were transferred at 3- to 4-day intervals to fresh medium.

In one series the developing larvae and pupae were subjected to 35° and 40° C. for 2, 4, 8, and 16 hours daily. When the insects were not under exposure, they were maintained at 25°. A check group was kept continuously at 25°. Exposures were continued throughout the larval and pupal periods, and on emergence females were held at 25° without further exposure to the higher temperatures.

In the series in which the adults were exposed, the larvae were reared at a constant 25° C. When the moths emerged, eight replicates were exposed to 35° and 40° for 2, 4, 8, and 16 hours daily until approximately 90 percent of the eggs had been laid.

The ovipositing moths were exposed in quart ice cream containers, 4⅜ inches in diameter, lined with plastic bags and covered with sections of paper toweling in a manner similar to that described by Patana.[4] The moths were fed 5-percent honey solution from 1-dram vials inserted through a hole in the toweling covers. Strips of paper toweling were placed in the containers to provide a surface for oviposition. The eggs laid by moths in each replicate were counted at 2-day intervals. Two pairs of moths of each species were placed in each ovipositional cage except the pink bollworm. One pair of pink bollworms was held in 8-ounce waxed paper cups with screen lids. Small squares of paper mesh toweling served as the oviposition site. The mesh toweling was placed on the upper surface of the screen and weighted down with a large metal washer. The female pink bollworm moths readily oviposited through the screen onto the toweling.

All ovipositing moths were held at a relative humidity of 40 to 60 percent. Photoperiods of 12 hours of fluorescent light and 12 hours of darkness were employed.

The hatch of eggs was determined by withdrawing a sample from each group of eggs and holding them at 40-percent relative humidity and 25° C. At the end of 5 days the percent hatch was determined by counting the hatched and unhatched eggs.

Moths of several of the species were reared and held in a manner similar to that previously described. The females were dissected and the spermathecas examined microscopically for the presence of spermatozoa.

RESULTS

Bollworm

The larval-pupal development period of the bollworm was shortest when it was reared with a daily exposure at 35° C. for 16 hours (table 1), with some reduction at 8 hours. At 40°, 2- and 4-hour daily exposures had little effect on the development period of the bollworm. However, when the exposure was increased to 8 hours, the development was prolonged. At 16 hours' exposure the bollworm moths failed to emerge.

The percentage of larvae pupating was not affected until the exposure was increased to 16 hours at 40° C. However, with 8- and 16-hour exposures at this temperature the percentage of misshapen pupae was high and the adults failed to emerge from the misshapen pupae. When larvae and pupae were exposed to 35°, emergence was not affected. At 40°, emergence decreased at 2- and 4-hour exposures, with little emergence at 8 hours and none at 16 hours.

Some oviposition occurred in all replicates of moths reared from larvae and pupae exposed to the various daily periods at 35° and 40° C. Fecundity of the females was not affected for 2 to 16 hours' exposure at 35° or for 2 to 4 hours at 40°. However, the fecundity of the emerging females was drastically reduced when exposed for 8 hours daily to 40°. Viability of the eggs laid by females reared from larvae exposed for 16 hours daily to 35° was reduced to some extent. Eggs laid by the females exposed for 4 and 8 hours daily to 40° failed to hatch.

Longevity of moths from larvae at the several exposure periods at 35° or 40° C. was not affected, except moths from larvae reared at 8 hours' daily exposure at 40° were significantly shorter lived.

Fecundity of the moths reared at a constant 25° C. and then exposed to the several periods at 35° was not affected, except fecundity and fertility were drastically reduced in moths from larvae reared at 16 hours' daily exposure. Some infertility would be expected because some eggs would have been exposed for from less than 1 to 32 hours during the 2-day ovipositional periods. The various exposures at 35° had no apparent effect on the longevity of the moths.

A 2-hour daily exposure to 40° C. did not adversely affect the fecundity and the fertility of the moths. The 4-hour daily exposure to this temperature had an insignificant effect on the fertility of the eggs laid by these moths. Fecundity was significantly reduced in moths exposed to 8 hours daily and drastically reduced by a 16-hour exposure. None of the eggs hatched

[4] Patana, R. Rearing cotton insects in the laboratory. U.S. Dept. Agr. Prod. Res. Rpt. 108, 6 pp. 1969.

from moths exposed to 8 and 16 hours. Though unpublished data of R. E. Fye and D. E. Surber indicated that from 60- to 100-percent infertility could be expected, there probably was some sterilization of the females before oviposition.

Dissection of from two to five females reared, mated, and exposed under similar conditions revealed spermatozoa in all the females from groups corresponding to those that laid fertile eggs in the experimental groups. No large spermatozoa were present in the dissected females from groups corresponding to those in which infertile eggs were laid. The data suggest that production of male spermatozoa as well as fecundity of the female may be affected by the extended exposure to 35° and 40° C. The data concur with the results of Jackson et al.,[5] who treated *H. zea* pupae for 1.5 hours at 41° and found that spermatophore transfer occurred between treated males and treated and untreated females, but eggs from the matings did not hatch.

Tobacco Budworm

The results of the studies with the tobacco budworm are given in table 1. The larval-pupal development period of the tobacco budworm decreased as the daily exposure of the larvae and pupae was increased from 2 to 16 hours at 35° C. However, at 40° with the 2-, 4-, and 8-hour daily exposures the development was similar to that of the control insects; at 16 hours the moths did not emerge.

Most of the larvae exposed daily to 35° and 40° C. for 2, 4, and 8 hours pupated normally, but pupation was drastically reduced when they were exposed for 16 hours to 40°. In the shorter exposures few of the pupae were misshapen; however, a marked increase in misshapen pupae occurred at 8 hours' exposure to 40° and 56 percent of the pupae from insects exposed to 16 hours were misshapen. Emergence of the moths from the pupae was normal in the groups exposed to 35° and in the 2- and 4-hour exposure groups at 40° daily. However, only about 25 percent of the moths emerged from larvae exposed for 8 hours daily. Most of the females oviposited.

There was no apparent effect on the fecundity and fertility of the females exposed for 2, 4, 8, and 16 hours daily to 35° C. in the larval-pupal stages. The fecundity of moths emerging from the larvae and pupae exposed to 40° for 2 hours daily was not affected, though fertility was significantly reduced. Fecundity of moths from larval-pupal exposure to 40° for 4 and 8 hours was reduced and they laid no fertile eggs. Longevity of the moths was unaffected by the various daily exposures of larvae and pupae to 35° and 40°.

Dissections of similarly reared moths 5 days after emergence indicated a pattern of the presence of live spermatozoa in the spermathecas comparable with the pattern of fertile eggs laid by the females emerging from the larvae and pupae held at the several exposures.

Fecundity, fertility, and longevity of moths from larvae reared at a constant 25° C. exposed for 2, 4, and 8 hours at 35° were not adversely affected. Daily exposure of the moths for 16 hours at 35° reduced the fecundity 25 percent and none of the eggs hatched. According to R. E. Fye and D. E. Surber (unpublished), most of the eggs should have hatched under the conditions they were held. The data therefore suggest that the continuing daily exposure for 16 hours at 35° had some deleterious effect on fecundity and fertility though longevity was unaffected.

The fecundity of the moths exposed for 2, 4, and 8 hours daily to 40° C. was unaffected, although fertility decreased as the daily exposure was increased. According to Fye and Surber (unpublished), exposure of eggs should have had little effect on hatch. Therefore the decline in egg hatch as the exposure period was increased may be attributed to the effect of the high temperatures on the moths. A similar tendency for a reduced longevity is also evident. When the females were exposed to 40° for 16 hours daily, the fecundity dropped to 25 to 33 percent of that for the moths in the other exposures. Along with the reduced fecundity was a marked decrease in the egg hatch and reduced longevity.

Dissection of a parallel set of moths indicated a pattern of live spermatozoa in the spermathecas similar to the pattern of fertile eggs laid by the study insects.

Beet Armyworm

Data for the beet armyworm are presented in table 1. Development periods of the beet armyworm exposed for the several periods at 35° C. were reduced as the daily exposure was increased. The exposures had no effect on pupation, occurrence of misshapen pupae, adult emergence, or percentage of moth replicates ovipositing. The fecundity and fertility of moths from larvae and pupae exposed to 35° for 2, 4, and 8 hours daily were not affected. When the larvae and pupae were exposed for 16 hours to 35°, fecundity and fertility of the moths were decreased; longevity was not affected.

Daily exposures of larvae and pupae of the beet armyworm to 2, 4, and 8 hours at 40° C. reduced the development period as periods of ex-

[5] JACKSON, R. D., DAUGHERTY, D. M., and DAVIDSON, J. L. EFFECT OF HEAT ON HELIOTHIS ZEA PUPAE. Amer. Ent. Soc. No. Cent. Br. Proc. 23: 36. 1968.

TABLE 1.—*Effects of 4 exposure periods at 2 temperatures on development, fecundity, fertility, and longevity of 6 lepidopterous pests of cotton in Arizona*

Temperature and daily exposure (hours)	Larval and pupal exposure										Adult exposure				
	Development period		Pupating	Misshapen pupae[1]	Emergence from pupae[1]	Replicates ovipositing	Eggs per replicate	Hatch[2]	Longevity[3]		Replicates ovipositing	Eggs per replicate	Hatch[2]	Longevity[3]	
	Males	Females							Males	Females				Males	Females
	Days	*Days*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*	*Percent*	*Days*	*Days*	*Percent*	*Number*	*Percent*	*Days*	*Days*
BOLLWORM															
35° C.															
0	30 ± 1	29 ± 1	95	0	97	100	1,786 ± 1,106	81	12 ± 1	13 ± 2	88	1,220 ± 1,045	77	10 ± 4	11 ± 3
2	31 ± 2	29 ± 3	97	0	100	75	1,414 ± 973	82	11 ± 3	11 ± 4	100	1,385 ± 1,021	81	9 ± 4	9 ± 4
4	29 ± 1	29 ± 2	91	3	95	100	1,939 ± 1,129	68	12 ± 2	12 ± 3	100	1,208 ± 741	78	9 ± 4	11 ± 4
8	26 ± 1	26 ± 2	95	8	92	100	2,165 ± 504	77	13 ± 2	12 ± 4	100	1,514 ± 848	89	9 ± 3	11 ± 3
16	24 ± 1	23 ± 1	98	2	95	100	1,258 ± 743	25	11 ± 4	13 ± 3	88	496 ± 495	0	8 ± 4	11 ± 4
40° C.															
2	31 ± 1	30 ± 2	100	6	89	100	1,527 ± 805	88	11 ± 2	12 ± 3	87	1,232 ± 1,162	68	11 ± 2	10 ± 4
4	34 ± 2	32 ± 2	97	3	83	100	1,441 ± 368	0	10 ± 2	14 ± 1	87	870 ± 881	58	8 ± 3	10 ± 4
8	36 ± 2	34 ± 2	92	19	[4]44	100	264 ± 70	0	6 ± 6	11 ± 4	100	653 ± 465	0	5 ± 3	7 ± 3
16	-	-	51	43	0	-	-	-	-	-	87	69 ± 55	0	5 ± 2	5 ± 2
TOBACCO BUDWORM															
35° C.															
0	32 ± 1	30 ± 2	95	0	[5]96	100	2,433 ± 509	47	12 ± 1	14 ± 0	100	1,658 ± 790	47	12 ± 1	14 ± 0
2	33 ± 1	30 ± 1	88	0	100	100	2,417 ± 411	42	12 ± 1	14 ± 1	100	1,649 ± 851	51	12 ± 1	14 ± 0
4	30 ± 1	29 ± 1	87	2	[5]90	100	2,773 ± 321	68	13 ± 1	14 ± 0	88	1,979 ± 975	55	12 ± 1	14 ± 0
8	27 ± 1	26 ± 1	93	2	91	100	2,639 ± 559	56	12 ± 1	14 ± 0	100	2,360 ± 241	59	12 ± 1	14 ± 0
16	24 ± 1	24 ± 2	100	4	96	100	1,980 ± 368	40	13 ± 1	14 ± 1	100	780 ± 456	0	12 ± 1	14 ± 0
40° C.															
2	33 ± 1	31 ± 1	93	2	96	100	1,782 ± 705	18	12 ± 1	14 ± 0	100	1,469 ± 514	40	12 ± 1	14 ± 1
4	34 ± 1	33 ± 1	98	2	[5]83	86	1,140 ± 710	0	12 ± 1	14 ± 0	100	1,253 ± 453	27	9 ± 4	12 ± 4
8	34 ± 1	32 ± 1	88	9	[5]26	100	549 ± 220	0	12 ± 0	14 ± 0	100	1,037 ± 540	13	9 ± 4	13 ± 3
16	-	-	27	56	[5]0	-	-	-	-	-	100	296 ± 210	0	7 ± 4	11 ± 4
BEET ARMYWORM															
35° C.															
0	21 ± 1	20 ± 1	92	9	91	100	2,025 ± 830	81	6 ± 0	7 ± 0	100	2,047 ± 348	92	7 ± 1	7 ± 0
2	21 ± 1	19 ± 0	96	4	94	100	1,997 ± 209	95	5 ± 0	7 ± 1	100	1,834 ± 344	86	6 ± 1	7 ± 0
4	19 ± 1	18 ± 1	94	0	100	100	1,949 ± 652	86	6 ± 1	7 ± 0	100	1,914 ± 387	73	6 ± 1	7 ± 0
8	17 ± 0	17 ± 1	94	2	98	100	2,390 ± 530	90	6 ± 1	7 ± 1	100	1,774 ± 445	88	7 ± 1	7 ± 0
16	15 ± 0	15 ± 1	94	7	91	100	1,476 ± 495	76	7 ± 0	7 ± 1	86	466 ± 463	24	6 ± 1	7 ± 0
40° C.															
2	20 ± 1	20 ± 1	98	0	94	100	2,068 ± 465	75	7 ± 1	7 ± 0	100	1,695 ± 652	76	6 ± 0	7 ± 1
4	19 ± 1	19 ± 1	100	4	84	100	1,550 ± 577	78	6 ± 1	7 ± 0	100	1,803 ± 370	66	6 ± 1	7 ± 1
8	18 ± 1	18 ± 1	88	7	89	100	894 ± 559	45	6 ± 1	7 ± 0	100	1,267 ± 635	43	6 ± 1	7 ± 1
16	-	-	88	77	16	-	-	-	-	-	100	309 ± 339	4	6 ± 1	7 ± 0

CABBAGE LOOPER

35° C.															
0	20 ± 1	19 ± 1	97	0	97	100	1,863 ± 737	71	13 ± 2	14 ± 0	100	1,888 ± 800	68	14 ± 0	14 ± 0
2	20 ± 1	19 ± 1	99	0	99	100	1,688 ± 419	71	13 ± 1	14 ± 1	100	1,950 ± 332	64	13 ± 0	14 ± 0
4	19 ± 1	19 ± 0	97	0	100	100	1,868 ± 372	77	13 ± 1	14 ± 1	100	1,775 ± 547	61	14 ± 0	14 ± 0
8	18 ± 0	18 ± 1	96	2	92	100	1,687 ± 671	78	14 ± 1	13 ± 2	100	1,289 ± 765	78	14 ± 0	14 ± 0
16	17 ± 1	17 ± 1	97	6	93	100	561 ± 274	33	14 ± 1	13 ± 3	88	42 ± 25	0	14 ± 0	14 ± 0
40° C.															
2	22 ± 1	21 ± 1	93	0	97	100	1,565 ± 489	60	13 ± 1	13 ± 2	100	1,433 ± 612	52	14 ± 1	14 ± 1
4	24 ± 1	23 ± 1	95	0	94	100	852 ± 513	47	13 ± 1	14 ± 1	100	415 ± 327	20	12 ± 2	12 ± 2
8	26 ± 1	25 ± 2	89	16	55	100	225 ± 179	0	8 ± 3	14 ± 1	38	24 ± 34	0	7 ± 2	7 ± 2
16	--------	--------	0	--------	--------	--------	--------	--------	--------	--------	0	--------	--------	6 ± 1	6 ± 1

SALT-MARSH CATERPILLAR

35° C.															
0	32 ± 1	31 ± 1	100	0	98	100	1,381 ± 773	81	6 ± 1	7 ± 0	100	1,717 ± 1,010	66	7 ± 1	6 ± 1
2	32 ± 1	31 ± 2	85	12	88	100	1,201 ± 543	81	6 ± 4	7 ± 0	100	1,267 ± 559	56	6 ± 1	6 ± 1
4	31 ± 2	30 ± 1	88	6	94	100	970 ± 422	83	6 ± 2	7 ± 0	100	1,386 ± 870	72	6 ± 1	6 ± 2
8	29 ± 1	29 ± 1	95	5	95	88	413 ± 352	0	7 ± 1	7 ± 0	100	1,309 ± 778	74	6 ± 1	6 ± 1
16	29 ± 2	30 ± 2	83	3	97	100	811 ± 632	0	7 ± 1	7 ± 0	100	1,107 ± 503	29	4 ± 1	6 ± 2
40° C.															
2	34 ± 2	33 ± 2	98	3	[6]95	100	597 ± 291	0	6 ± 1	7 ± 1	100	1,298 ± 416	49	5 ± 1	6 ± 1
4	37 ± 3	37 ± 3	95	13	96	60	143 ± 229	0	7 ± 1	7 ± 0	100	1,008 ± 436	3	4 ± 1	4 ± 1
8	--------	--------	65	92	0	--------	--------	--------	--------	--------	100	339 ± 258	0	3 ± 1	4 ± 1
16	--------	--------	0	--------	--------	--------	--------	--------	--------	--------	63	52 ± 57	0	3 ± 1	3 ± 1

PINK BOLLWORM

35° C.															
0	27 ± 2	26 ± 2	58	0	[7]95	70	178 ± 188	76	14 ± 3	14 ± 2	92	435 ± 256	64	15 ± 0	14 ± 1
2	26 ± 1	24 ± 2	68	0	[7]96	100	354 ± 127	56	15 ± 1	15 ± 0	67	262 ± 232	65	15 ± 0	14 ± 2
4	25 ± 1	24 ± 1	68	0	96	100	185 ± 184	66	15 ± 1	15 ± 1	67	170 ± 251	44	15 ± 0	15 ± 0
8	24 ± 2	24 ± 1	73	0	94	100	390 ± 126	70	15 ± 0	15 ± 1	67	237 ± 254	57	15 ± 0	15 ± 1
16	23 ± 2	23 ± 2	71	0	80	59	62 ± 116	31	14 ± 2	14 ± 1	33	32 ± 77	18	14 ± 1	14 ± 2
40° C.															
2	28 ± 2	28 ± 3	59	0	90	75	238 ± 190	72	15 ± 0	15 ± 0	90	230 ± 208	48	14 ± 2	14 ± 2
4	27 ± 2	28 ± 3	66	0	79	92	122 ± 125	61	15 ± 1	14 ± 3	75	116 ± 186	16	15 ± 0	14 ± 2
8	32 ± 1	29 ± 1	39	4	58	67	6 ± 6	0	11 ± 4	10 ± 5	45	46 ± 75	9	14 ± 2	14 ± 1
16	--------	39	11	86	0	--------	--------	--------	--------	--------	0	--------	--------	10 ± 4	13 ± 3

[1] Based on number of pupae.
[2] Corrected by Abbott's formula.
[3] Survivors at conclusion of test considered to have longevity of study period: Bollworm and tobacco budworm (14 days), beet armyworm and salt-marsh caterpillar (7 days), and cabbage looper and pink bollworm (15 days).
[4] 1 male in aestivation.
[5] Number aestivating. At 35° C., 1 male in check and 1 male and 1 female in 4 hours; at 40°, 4 males in 4 hours, 16 males and 1 female in 8 hours, and 3 females in 16 hours.
[6] 1 male in aestivation.
[7] 1 female in diapause.

posure increased, but they had little effect on pupation, percentage of misshapen pupae, adult emergence, or percentage of moth replicates ovipositing. However, when the daily exposure was increased to 16 hours, moth emergence was reduced and the emerged, misshapen moths did not oviposit. Actually the percentage of misshapen pupae was extremely high, indicating an extremely adverse effect of the prolonged high temperature on pupation. Fecundity of the moths emerging from the larvae exposed for 2 and 4 hours daily to 40° was not affected. However, when the daily exposure of the larvae and pupae was increased to 8 hours, the fecundity was reduced 50 percent and the fertility of the eggs was markedly decreased. The exposure of the larvae and pupae to 40° had no effect on the longevity of the adults.

Exposure of adult moths reared at a constant 25° C. and then subjected to daily exposures of 2, 4, and 8 hours at 35° did not affect their fecundity, fertility, or longevity. However, when the daily exposure of the adults was increased to 16 hours, fecundity of moths and egg hatch were both reduced by 67 percent as compared with fecundity and egg hatch of moths subjected to shorter exposures. Exposure of the larvae and pupae to 35° did not affect adult longevity.

Daily exposures of the adults reared at a constant 25° C. for 2 and 4 hours at 40° did not affect fecundity or fertility. However, when the daily exposure was increased to 8 hours, fecundity was reduced slightly and the fertility 33 percent. When the daily exposure was increased to 16 hours, fecundity was reduced 75 percent and egg hatch about 96 percent. Longevity of the moths exposed to various periods at 40° daily was not affected.

Periods of high temperatures drastically affected the fecundity and fertility of beet armyworms. These results readily explain the early- and late-season occurrence of the pest in Arizona cotton.

Cabbage Looper

Data for the cabbage looper are given in table 1. The development period decreased as the daily exposure of larvae increased from 2 to 16 hours at 35° C. Pupation was unaffected. However, a small percentage of misshapen pupae occurred among the insects subjected to 8 and 16 hours' exposure daily and emergence decreased slightly. Moths in all the replicates oviposited, but fecundity of those from larvae reared at a daily exposure of 16 hours at 35° was about one-third that of the moths from larvae reared at the other exposures. Egg hatch of females from larvae and pupae reared at 16 hours' daily exposure to 35° was about one-half that of the moths from larvae reared at the other exposures. Longevity was unaffected by increased hours of daily exposure to 35°.

Development time of larvae exposed at various intervals to 40° C. was increased, but the percentage of insects pupating was slightly decreased. When the daily exposure was increased to 16 hours, none of the insects developed to the pupal stage. Among the insects reared at 40° for 8 hours' exposure daily, a large percentage of the pupae was misshapen and adult emergence was poor. Females in all the replicates oviposited, and the daily exposure of the larvae and pupae for 2 hours at 40° did not reduce fecundity, though fertility was slightly lower than that of insects reared at 35°. The moths from pupae reared with daily exposures of 4 hours at 40° had a fecundity of about one-half that of the moths reared without exposure and of those exposed for 2 to 8 hours at 35°. Fertility of the eggs was about two-thirds that of eggs from the control insects. When exposure was increased to 8 hours daily, fecundity was drastically reduced and the eggs failed to hatch. Longevity of the moths reared from larvae and pupae exposed for 2 and 4 hours at 40° daily was not affected, though the longevity of the male moths from larvae and pupae exposed for 8 hours daily was reduced by one-third.

Daily exposure of moths reared at a constant 25° C. to 2-, 4-, and 8-hour daily periods at 35° did not affect their fecundity or fertility. However, when their daily exposure was increased to 16 hours at 35°, fecundity was drastically reduced and eggs did not hatch. The 2- to 16-hour daily exposure to 35° did not affect moth longevity.

Daily exposure of the moths from larvae reared at a constant 25° C. to a 2-hour period at 40° did not affect the fecundity but reduced fertility slightly. Daily exposures of 4 and 8 hours markedly decreased fecundity and the 8-hour exposure reduced fecundity to a few eggs. Fertility of the moths in the 4-hour daily exposure was reduced about two-thirds and in the 8-hour exposure to 0. Moths exposed to 40° daily for 16 hours did not oviposit. As the exposure period was increased, moth longevity at 8 and 16 hours was reduced to about 6 days.

The data in table 1 clearly indicate why cabbage looper damage to cotton in southern Arizona is restricted to late in the season when the canopy of the cotton plant is cooled to below 38° C.[6] Early in the season the temperatures within the canopy are similar to the air temperature and the daily extremes commonly exceed 38°. Therefore increased development period, de-

[6] Fye, R. E., and Bonham, C. D. TEMPERATURE IN THE PLANT PARTS OF LONG STAPLE COTTON. Jour. Econ. Ent. 64: 636–637. 1971.

creased fecundity, decreased fertility, and a reduced egg hatch result in low populations in the early hot part of the cotton-growing season.

Salt-Marsh Caterpillar

Data for the salt-marsh caterpillar are presented in table 1. Exposures of 2 and 4 hours daily at 35° C. of larvae and pupae had no effect on the development period. However, when the exposure was increased to 8 and 16 hours, the development period was reduced slightly. Exposures of the larvae and pupae had no effect on pupation, percentage of misshapen pupae, adult emergence, or percentage of moth replicates ovipositing. Exposures of the larvae and pupae to 2- and 4-hour daily periods at 35° had no effect on the fecundity of the moths. However, when the periods were increased to 8 and 16 hours, the fecundity was reduced and no eggs hatched. The exposures had no effect on moth longevity.

Daily exposure of the larvae to 40° C. for 2 and 4 hours increased the development period. The 2-hour exposure had no effect on pupation, percentage of misshapen pupae, adult emergence, or percentage of moth replicates ovipositing. However, fecundity was markedly reduced compared with that of the control insects and none of the eggs hatched. The 4-hour exposure did not reduce pupation, increased the percentage of misshapen pupae, did not decrease adult emergence, and markedly decreased the percentage of moth replicates ovipositing. Fecundity was markedly reduced and eggs did not hatch. The 2- and 4-hour daily exposures to 40° had no effect on the longevity of moths. Larvae reared at 8 hours' daily exposure to 40° failed to pupate properly, 92 percent of the pupae were misshapen, and no moths emerged. When the daily exposure was increased to 16 hours at 40°, none of the larvae pupated.

According to unpublished data of R. E. Fye and D. E. Surber, no adverse effect should have been expected on eggs laid by moths held at 25° C. Therefore the daily exposure of the larvae and pupae to 8 and 16 hours at 35° had some effect on egg hatch. In the case of moths reared from larvae exposed to 2 and 4 hours daily at 40°, no adverse effect on eggs would be expected when the moths were held at 20°. Therefore we may conclude that daily exposure of larvae and pupae to 40° had some deleterious effect on fertility of the females.

Exposure of moths from larvae reared at a constant 25° C. and held for 2 to 16 hours at 35° failed to reduce their fecundity. However, at 16 hours' exposure the fertility was reduced to a level lower than would be expected according to data of Fye and Surber (unpublished). The longevity of the male moths exposed for 16 hours daily to 35° was also reduced.

Exposure of moths reared at a constant 25° C. to daily periods of 2 and 4 hours at 40° did not reduce the fecundity, although the fertility was drastically reduced in the 4-hour exposure. The failure of eggs to hatch would be expected according to the data of Fye and Surber (unpublished), who showed that exposure of salt-marsh caterpillar eggs for 4 hours to 40° and 40-percent relative humidity resulted in no hatch. Exposure of the moths from larvae reared at a constant 25° to 8 hours at 40° daily reduced the fecundity to a low level and none of the eggs hatched. When the exposure was increased to 16 hours daily at 40°, fewer moths oviposited, fecundity was reduced, and eggs did not hatch. At 8- and 16-hour exposures to 40°, longevity of the moths was reduced appreciably.

Dissection of a parallel set of moths 5 days after emergence and pairing of males and females showed motile spermatozoa in the spermatheca of the females in the same pattern as that of fertile eggs laid by the test females. The one exception was in moths reared from larvae and pupae exposed to 35° C. for 8 hours daily. The dissected females had live spermatozoa in the spermatheca, but eggs of the study females failed to hatch. This suggests that the high temperature affected the fertility of the females or the fertilizing capacity of the male spermatozoa.

The data in conjunction with unpublished reports of Fye and Surber and Fye and McAda account for the absence of the salt-marsh caterpillar in the early part of the cotton-growing season in Arizona. The high temperatures early in the season prolong the development period and reduce reproduction.

Pink Bollworm

Data for the pink bollworm are presented in table 1. The development period of the larvae and pupae decreased as the daily exposure to 35° C. was increased from 2 to 16 hours. The several daily exposures to 35° had no effect on pupation, percentage of misshapen pupae, adult emergence, or percentage of females ovipositing. The one exception was in the 16-hour daily exposure when adult emergence and percentage of females ovipositing decreased. The fecundity of the females reared from larvae exposed for 2 to 8 hours daily was highly variable, but percentages of hatched eggs were similar. When the exposure period of the larvae and pupae was increased to 16 hours, fecundity was reduced by about 67 percent and fertility by 50 percent. The longevity of moths emerging from larvae and pupae exposed from 2 to 16 hours daily was similar.

The development period of pink bollworms exposed for 2 to 8 hours daily to 40° C. in the larval and pupal stages was extended slightly

over that of those reared at 35°. A single female from larvae and pupae exposed for 16 hours daily required 39 days for development. Daily exposures of larvae and pupae for 2 and 4 hours to 40° did not affect pupation, adult emergence, or percentage of moth replicates ovipositing. Daily exposures of the larvae and pupae for 8 hours to 40° reduced pupation, increased the percentage of misshapen pupae, and decreased moth emergence and the percentage of moth replicates ovipositing. When the daily exposure was increased to 16 hours, the percentage of larvae pupating was very limited, a large percentage of the pupae was misshapen, and no moths emerged. Exposure of the larvae and pupae for 2 and 4 hours daily to 40° did not decrease fecundity nor egg hatch, though fecundity among the moths emerging from larvae and pupae exposed for 4 hours tended to decrease. The fecundity of moths emerging from larvae and pupae exposed for 8 hours daily to 40° was markedly decreased and no eggs hatched. Longevity of moths emerging from larvae and pupae exposed for 2 and 4 hours daily to 40° was not affected, but the longevity of those exposed for 8 hours daily was decreased slightly.

Fecundity of moths from larvae reared at a constant temperature of 25° C. and then exposed for 2, 4, and 8 hours daily to 35° was highly variable but was not affected. Hatch of eggs was not affected. However, when daily exposure of moths was increased to 16 hours, fecundity and fertility were drastically reduced. The longevity of the moths in the 2- to 16-hour daily exposure was not affected.

A decline in the fecundity of the moths and a marked decrease in egg hatch occurred as the exposure of moths from larvae reared at 25° C. was increased from 2 to 8 hours daily at 40°. Longevity was not affected. When pink bollworm adults from larvae reared at a constant temperature of 25° were exposed daily for 16 hours to 40°, none of the moths oviposited and longevity was abbreviated.

Thus the effects of high temperatures on the pink bollworm are similar to the data presented for the other species, and the explosive nature of the pink bollworm populations in southern Arizona late in the season may be explained as a bioclimatic release. At the release the major suppression factor, temperature, is modified by shading in the plant canopy, and rapid development, improved fecundity, and larger egg hatch result in increased populations.

DISCUSSION

Generally the effects of the several periods of higher temperatures were the same for the six lepidopterous pests of cotton in Arizona, and the patterns for development, fecundity, and fertility were similar. The data in conjunction with unpublished reports on egg hatch by Fye and Surber, the development, fecundity, and longevity data by Fye and McAda (unpublished), and the temperature modification within cotton presented by Fye and Bonham[7] partially explain the low populations of these injurious insects in cotton early in the season in Arizona. When the temperatures are amply modified by the increasing cotton plant canopy, the sites occupied by the various stages of these insects are cooled and development, fecundity, and fertility return closer to a "normal" level. When this occurs, the exponential form of the population curve is regained.

The boll weevil (*Anthonomus grandis* Boheman) is bioclimatically controlled early in the season but is released by the temperature modification due to shading within the plant canopy and on the soil surface late in the season according to Fye and Bonham (unpublished). This insect reflects the same reaction to high temperatures as the six major cotton pests described in this report.

The data also suggest that short daily periods at 40° C. may partially sterilize the moths although they retain activity potential and longevity. In fact all the adults reared from larvae and pupae held for 4 or more hours at 40° were extremely active and highly agitated. The reactions of the insects to the extended daily periods of 40° during rearing suggest that partial sterilization by the elevated-temperature programs, followed by a low dose of irradiation to complete the sterilization, may be a practical method for retaining the aggressiveness and longevity of the moths destined for sterile-male introduction.

[7] See footnote 6.

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